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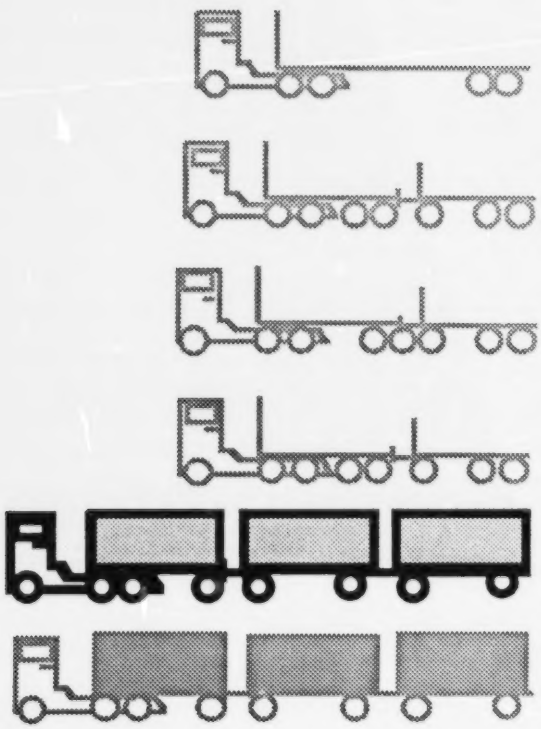
Demonstration of Baseline Vehicle Performance: A-Train Triple



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Demonstration of Baseline Vehicle Performance: A-Train Triple

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Prepared for:
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Abstract:
An A-train triple trailer was tested by the Ontario Ministry of Transportation and Communications as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

Key Words: truck testing, offtracking, truck turning, air brake system, braking, truck dynamic tests, rearward amplification, rollover, lane change, tilt test

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ABSTRACT

An A-train triple trailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated a base-line vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

TABLE OF CONTENTS

PAGE

1/ INTRODUCTION 1

2/ TEST VEHICLE DESCRIPTION 2

3/ TEST PROGRAM 5
3.1/ Test Procedures 5
3.2/ Instrumentation 6
3.3/ Data Capture and Data Processing 6

4/ RESULTS 8
4.1/ Offtracking 8
4.2/ Right-Hand Turn 8
4.3/ Channelized Right Turn 9
4.4/ Air Brake System 9
4.5/ Straight-Line Braking 12
4.6/ Evasive Manoeuvre 12
4.7/ Sinusoidal Steer 13
4.8/ Lane Change 15
4.9/ Normal Straight-Line Driving 16
4.10/ Steady Circular Turn 17

5/ DISCUSSION 18

6/ CONCLUSIONS 19

7/ REFERENCES 20

LIST OF FIGURES

PAGE

1/ A-Train Triple, View of Vehicle 22
2/ A-Train Triple, Vehicle Dimensions. 22
3/ A-Train Triple, Clockwise Offtracking 23
4/ A-Train Triple, Counter-Clockwise Final Offtracking 23
5/ A-Train Triple, Right-Hand Turn Swept Path. 24
6/ A-Train Triple, Right-Hand Turn 25
7/ A-Train Triple, Channelized Right Turn. 25
8/ A-Train Triple, Channelized Right-Turn Clearance from Inner Curb. 26
9/ A-Train Triple Trailer and Dolly, Air Brake System Schematic 27
10/ A-Train Triple, Air Brake Application and Release 28
11/ A-Train Triple, Vehicle Response to Straight-Line Braking . . 29
12/ A-Train Triple, Straight-Line Braking Responses vs Treadle Valve Pressure. 30
13/ A-Train Triple, Evasive Manoeuvre, Peak-to-Peak Responses vs Speed. 31
14/ A-Train Triple, Vehicle Response in Evasive Manoeuvre 32
15/ A-Train Triple Vehicle Making Evasive Manoeuvre 33
16/ A-Train Triple Vehicle Making Sinusoidal Steer. 33
17/ A-Train Triple, Rearward Amplification of Lateral Acceleration. 34
18/ A-Train Triple, Sinusoidal Steer, Trailer Responses at 94 km/h. 35
19/ A-Train Triple, Sinusoidal Steer, Rear Trailer Lateral Acceleration, 3 Test Speeds 36
20/ A-Train Triple, Lane Change, Response Summary vs Speed. . . . 37
21/ A-Train Triple, Lane Change, Vehicle Responses at 75 km/h 38
22/ A-Train Triple Vehicle Making Lane Change 39
23/ A-Train Triple Vehicle Making Steady Circular Turn. 39
24/ A-Train Triple, Steady Circular Turn, Vehicle Responses vs Tractor Lateral Acceleration 40
25/ A-Train Triple, Steady Circular Turn, Vehicle Responses at 54 km/h. 41

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1/ INTRODUCTION

The effects of changes in truck weight and dimension parameters on combination vehicle stability and handling and on pavement response to axle group loading are being examined in the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle portion of the study involved both computer simulation of vehicle dynamic manoeuvres and testing of vehicles and components. Combination vehicles were classified into six families, based on the number of trailers and methods of hitching. A representative of each family was designated as the baseline vehicle configuration for that family. Additional vehicle configurations of interest were also defined. All baseline and additional vehicle configurations were tested to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures.

The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and three additional tractor-trailer combinations, as part of its contribution to the study. This report presents the results of a test of an A-train triple trailer combination baseline vehicle. It refers frequently to a report describing procedures and equipment common to tests of all nine vehicles undertaken by MTC [1]. Similar reports present details of the tests of the other eight vehicles [2-9], and a summary report presents the results of tests of all six baseline vehicles [10]. A computer simulation of vehicle responses to actual test inputs using estimated vehicle data has also been conducted [11].

2/ TEST VEHICLE DESCRIPTION

The test vehicle consisted of the MTC Freightliner [1] and three single-axle van-type semitrailers with single-axle A-type converter dollies. The combination is typical of equipment used in provinces where triple trailer combinations operate under special permit. The same combination was also tested concurrently as a C-train, using B-type converter dollies [6].

The equipment for these tests was obtained by the study from CP Express and Transport. No modifications were made to the trailers or dollies except for purposes of attachment of test equipment, which had no effect on the operation of the vehicle, though unit weights and polar moments of inertia were affected. The equipment was inspected before the test by a representative of the owner on behalf of the Canadian Trucking Association, with no deviations from specifications reported.

The trailers and dollies were brand new. They were manufactured by Trailmobile in February 1985. The trailers had serial numbers 2TCH281B6EA303117, 2TCH281B93A303130, and 25CH281B93A303127 and fleet numbers 7794, 7807, and 7804, from front to rear, respectively. The A-dollies had serial numbers 2TCT101AXEA303207 and 2TCT101A3EA303209 and fleet numbers 0747 and 0745 for front and rear, respectively.

Each trailer had a nominal length of 8.53 m (28 ft) and a nominal width of 2.59 m (102 in). Each trailer had a tapered nose section and a 1.22 m (4 ft) kingpin set back so that they could also be operated as a legal doubles combination in some provinces. The trailers were insulated, and a propane heater was installed at the front near the roof. The trailer suspension had a single tapered leaf spring and was rated at 9616 kg (21 155 lb). The spring spread was 1.09 m (43 in), and the track width was 2.59 m (102 in). The spring lash space was 38 to 41 mm (1.5 to 1.63 in). The trailers were equipped with an air-actuated no-slack pintle hook. The dollies had the same suspension as the trailers, a drawbar length of 2.13 m (84 in), and a fifth wheel set 25 mm (1 in) forward of the axle centreline. The combination had an overall length of 31.08 m (102 ft).

The trailers and dollies were fitted with new Michelin XZA radial tires, in load range H and size 11R22.5. These tires were run a nominal distance of 160 km (100 mi) before any testing and were then, subsequently, used for all tests. Tire pressure was set cold at 689 kPa (100 psi),

which is the manufacturer's recommended value for full load. This was used for all tests and represents the common operating practice of not reducing tire pressure when running empty.

The test vehicle is shown in Figure 1, in test condition with outriggers installed. The dimensions of the test vehicle are presented in Figure 2. Empty weight of the combination in test condition was 33 087 kg (72 790 lb). Concrete blocks were used to obtain a loaded weight of 55 942 kg (123 070 lb). Axle loads in these conditions are given in Table 1.

Table 1/ Axle Loads

Axle No.	Empty		Loaded	
	(kg)	(lb)	(kg)	(lb)
1	4 864	10 700	5 286	11 630
2	3 945	8 680	5 914	13 010
3	3 705	8 150	5 168	11 370
4	4 177	9 190	7 800	17 160
5	4 091	9 000	8 073	17 760
6	4 377	9 630	7 964	17 520
7	3 855	8 480	8 005	17 610
8	4 073	8 960	7 732	17 010
Total	33 087	72 790	55 942	123 070

The empty weight exceeds that which would normally be seen on the highway, because the tractor is considerably heavier than late-model equipment and because of the weight of test equipment installed, particularly the outriggers. The loaded weight is also somewhat greater than that allowed by provinces where this combination runs under special permit. Typical loaded weights on the highway for such combinations are often much less than that allowed, by the nature of the cargo carried by the vehicle. A target axle load of 8000 kg (17 600 lb) was set for all axles except for the steer axle. This was nearly attained, with the exception of the tractor drive axles, as all three trailers were loaded in the same fashion, consistent with normal practice. The tractor drive axles, therefore, were loaded less than each trailer axle, because their combined load was much less than 12 000 kg (26 400 lb) because of the empty vehicle.

The height of the centre of gravity of the empty trailer sprung mass was estimated as 0.40 m (16 in) above the top of the floor. The centre of gravity height was estimated as 0.33 m (13 in) above the top of the floor in the loaded condition.

3/ TEST PROGRAM

3.1/ Test Procedures

The test vehicle was prepared for testing in the following way:

1/ A mechanical inspection was carried out, and any necessary repairs or maintenance was done.
2/ Outrigger and safety cable attachments and load block retention sills were installed on the trailers, and safety cable attachments were installed on the dollies.
3/ Outriggers were installed on the trailers.
4/ The boxes containing instrument packages, power supplies and signal conditioning, other instruments, and cabling were installed.
5/ New tires were installed, and pressures were set.
6/ Other fittings necessary for testing were installed.
7/ Concrete blocks were located on the trailer beds to achieve specified axle loads.
8/ Notes were made from detailed physical inspection, including an inventory of components and measurement of dimensions.
9/ The MTC tractor was coupled to the trailers.
10/ The combination vehicle was weighed, empty and loaded.
11/ A functional test of the on-board electronics was conducted.
12/ Test runs were made to shake down the vehicle instrumentation and familiarize the test driver with the vehicle's handling characteristics.
13/ Tires were run a nominal distance of 160 km (100 mi).
14/ Articulation angle between the tractor and lead trailer was calibrated.
15/ Photographs and video film were taken to record details of the vehicle and test equipment.

The following tests were performed:

- Offtracking
- Right-hand turn
- Channelized right turn
- Air brake system
- Straight-line braking, empty vehicle, low-friction surface
- Evasive manoeuvre, empty vehicle, low-friction surface
- Sinusoidal steer, loaded vehicle, high-friction surface
- Lane change, loaded vehicle, high-friction surface
- Normal straight-line driving
- Steady circular turn, loaded vehicle, high-friction surface

All tests followed standard procedures [1], except as noted.

3.2/ Instrumentation

The instrumentation shown in Table 2 was installed. Brake pressure transducers were only installed in the trailers and dollies for the air brake system test, but all other instrumentation was installed for all tests. Data were always captured from all instrumentation, but only those pertinent to a particular test were analysed.

Tractor instruments were selected from the instrumentation that is permanently installed on the tractor. Instruments for the two front trailers were mounted in boxes placed inside the van on the trailer deck, which also contained power supplies and signal conditioning. Instruments for the rear trailer and dollies were wired into these boxes. Trailer lateral acceleration and roll angle were measured at a point midway between the kingpin and axle, which was very close to the trailer sprung mass centre of gravity.

Full details of the instrumentation, signal conditioning, and data capture system are presented elsewhere [1].

3.3/ Data Capture and Data Processing

Data were digitized on board the vehicle and transmitted by telemetry as a pulse-code modulated (PCM) data stream to a ground station, where they were recorded on magnetic tape and captured in real time by an HP-1000 computer system. Test data for a run were processed immediately after the run, and results from a series of runs were subsequently analysed using the computer system [1].

Many test runs of all types were conducted for this vehicle. Not all these runs were used in the preparation of this report. In a number of instances, a run failed to meet a test condition, or runs were made to evaluate the ability of the vehicle to make a particular manoeuvre.

Table 2/ Instrumentation Installed

No	Measurement	Instrument	Full Scale
1	Tractor steer angle	Spectrol 139 potentiometer	25.02°
2	Tractor roll angle	Humphrey CF18-0907-1 gyro package	8.85°
3	Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4	Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5	Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6	Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7	Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8	Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9	Tractor fifth wheel load right-hand side	MTC load cell	10 290 lb
10	Tractor treadle valve pressure	Celesco PLC-200G	100 psi
11	Tractor brake pressure, axle 2 Left	Celesco PLC-200G	99.80 psi
12	Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13	Tractor yaw angle	Humphrey CF18-0907-1 gyro package	17.73°
14	Trailer 1 articulation angle	Celesco pull cord DV-301-150	23.194°
15	Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16	Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyro	8.90°
17	Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18	Dolly 1 hitch angle	Spectrol 139 potentiometer	25.0°
19	Dolly 1 lateral acceleration	Columbia SA-107 accelerometer	0.996 g
20	Brake pressure, axle 4 right	Celesco PLC-200G	104.96 psi
21	Brake pressure, axle 5 right	Celesco PLC-200G	101.06 psi
22	Brake pressure, axle 6 right	Celesco PLC-200G	102.07 psi
23	Brake pressure, axle 7 right	Celesco PLC-200G	101.93 psi
24	Brake pressure, axle 8 right	Celesco PLC-200G	106.79 psi
25	Spare		
26	Spare		
27	Trailer 2 articulation angle	Spectrol 8409 potentiometer	22.8°
28	Trailer 2 lateral acceleration	Columbia SA-107 accelerometer	0.980 g
29	Trailer 2 roll angle	Humphrey VM02-0128-1 vertical gyro	8.91°
30	Trailer 2 outrigger touchdown	Strain gauge bridge	1.0 V
31	Dolly 2 hitch angle	Spectrol 139 potentiometer	25.0°
32	Dolly 2 lateral acceleration	Columbia SA-107 accelerometer	0.993 g
33	Trailer 3 articulation angle	Spectrol 8409 potentiometer	22.7°
34	Trailer 3 lateral acceleration	Columbia SA-107 accelerometer	0.986 g
35	Trailer 3 roll rate	Humphrey RT03-0502-1 angular rate transducer	80.85°/s
36	Trailer 3 outrigger touchdown	Strain gauge bridge	1.0 V

4/ RESULTS

4.1/ Offtracking

Steady-state offtracking is considered an indicator of vehicle turning ability. Offtracking of the vehicle was evaluated by making a complete turn around a circle of radius 29.87 m (98 ft). The vehicle outer wheel tracked the inside of the circle. Turns were made in both directions, as shown in Figure 3. At the end of a turn, the vehicle was parked and the radius to each axle was measured, according to the standard test procedure [1].

The results are shown in Table 3. The measured data were averaged for the left and right turn and then compared to data generated by a simple offtracking formula [12]. The difference between actual and computed values shown in the last column of Table 3 is so small that steady-state offtracking can clearly be estimated very accurately by this simple formula.

The final offtracking for the counter-clockwise turn is shown in Figure 4. After averaging for both directions and correcting for differences in axle track width, the offtracking of 2.68 m (8.79 ft), shown in Figure 4, became 2.77 m (9.09 ft).

Table 3/ Offtracking

Axle No.	Track Width (m)	Radius to Inner Wheel		Difference (m)	Average (m)	Calculated (m)	Difference %
		Right Turn (m)	Left Turn (m)				
1	2.31	27.45	27.47	0.02	27.46	27.56	+0.36
2	2.37	27.10	27.13	0.03	27.12	27.21	+0.33
3	2.37	27.07	27.08	0.01	27.07	27.21	+0.51
4	2.53	26.25	26.32	0.07	26.29	26.33	+0.15
5	2.53	26.20	26.27	0.07	26.24	26.27	+0.12
6	2.53	25.39	25.54	0.15	25.47	25.46	-0.04
7	2.53	25.31	25.49	0.18	25.40	25.39	-0.04
8	2.53	24.47	24.67	0.20	24.57	24.56	-0.04

4.2/ Right-Hand Turn

A 90° right-hand turn is a very demanding manoeuvre for a large truck. The vehicle's swept path in a 90° right-hand turn of 15 m (49.2 ft)

radius was measured, according to the standard test procedure [1]. This radius is typical in an urban area or where there is limited truck traffic. The swept path is shown in Figure 5.

The vehicle is shown in Figure 6 during the turn, at a point close to its maximum excursion out of the exit lane. The maximum excursion out of lane was 3.80 m (12.5 ft) or slightly over one lane width. It was out of the exit lane for a distance of 19.40 m (63.6 ft), as derived from Figure 5. This test was conducted at a creep speed and represents about the best possible turn. A rolling turn would probably result in a greater excursion out of the exit lane.

4.3/ Channelized Right Turn

The vehicle's swept path in a channelized right turn was measured according to the standard test procedure [1].

The vehicle is shown during the turn in Figure 7. The clearance of the innermost wheel of the rear trailer's rear axle from the inner curb is shown in Figure 8 as a function of distance through the curve. The minimum clearance was only 0.51 m (20 in) in the 5.5 m (18 ft) wide roadway.

The roadway geometry used for this test is typical of an urban area, where space is limited. The curb radius was 25 m (82 ft), and entry and exit tapers typical of four-lane roadways with a 60 km/h speed limit were used. The vehicle barely made it through the channel, with the left front wheel tracking right on the outer curb. In practice, a driver would allow some clearance on this side, if only to stay clear of catch basins. This would mean the rear axle would likely run over the inner curb. The test was run at creep speed, the worst condition, as the effect of lateral acceleration is to reduce the geometric offtracking measured in this test. However, in an urban area the truck driver cannot be guaranteed free-flowing traffic at such roadway geometry, so it is evident that this channelized right turn may limit access of such large combinations.

4.4/ Air Brake System

The air brake system of the combination was evaluated according to standard test procedure [1].

The trailer air brake system was inspected. A schematic of the system is shown in Figure 9. The dollies were equipped with a booster relay valve to speed the signal. All slack adjusters were automatic. Stroke was adjusted to the minimum, about 32 mm (1.25 in) on each axle. The tractor was supplied with shop air, regulated at 689 kPa (100 psi). Pressure transducers were installed at all trailer and dolly axles.

The SAE J982a style test was perfcrmed for the full triple combination; for the double, which resulted when air to the second dolly was shut off; and for the tractor-trailer when air to the first dolly was shut off. The results of these tests are presented in Tables 4, 5, and 6. A typical time history response of application and release for the full triple is presented in Figure 10. There appears to be something wrong with the two dolly valves, axles 5 and 7, as pressure did not rise fully. However, the timing of axles 7 and 8 on the rear trailer was very close. This is a desirable situation, because when a trailer axle is slower than its dolly axle, the inertia of the trailer pushes the dolly for a short time while the dolly axle is braking and the trailer axle is still rising to its steady pressure. This would provide a potential dolly jackknife situation in hard braking of an empty vehicle on a low-friction surface. The timing of axles 5 and 6 on the second trailer was not close.

Table 4/ Air Brake Timing, SAE J982a Style Test, Triple

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.07	0.18	95.6
Axle 2	0.37	0.58	95.0
Axle 4	0.54	1.42	92.6
Axle 5	0.57	1.50	88.9
Axle 6	0.85	1.92	93.1
Axle 7	0.95	1.95	77.0
Axle 8	0.97	2.05	92.4

Table 5/ Air Brake Timing, SAE J982a Style Test, Double

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.03	0.17	95.3
Axle 2	0.37	0.57	93.6
Axle 4	0.55	1.41	91.9
Axle 5	0.59	1.47	90.0
Axle 6	0.67	1.51	92.5

Table 6/ Air Brake Timing, SAE J982a Style Test, Semi

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.02	0.18	97.4
Axle 2	0.36	0.58	96.7
Axle 4	0.37	0.78	94.2

The results in these tables are the average of several tests in each case, each with a time resolution of 0.02 s.

The results when trailers were progressively added are interesting. As a semi (Table 6), application times for tractor and trailer were both 0.37 s, an ideal situation. When the second trailer was added (Table 5), the first trailer application time was prolonged to 0.55 s. When the rear trailer was added (Table 4), the second trailer application time was increased from 0.67 to 0.85 s. As each trailer was added, only the preceding trailer was affected, as the plumbing and valves prevented feedback to more than one trailer ahead. Similar results pertain for the release times.

The application times of the SAE J982a style test compare favourably with those obtained from a test conducted previously by MTC on another triple combination [13]. The release times are considered long, however, especially as it was shown that a quick-release valve operating with the booster relay valve could halve the release time [13]. The benefit to brake timing of the booster relay valves on the dollies is amply demonstrated when comparing timing results to triple combinations not so equipped [6,14].

4.5/ Straight-Line Braking

It is difficult to conduct rigorous braking tests and achieve consistent results. A demonstration of modes of instability of the combination vehicle in straight-line braking was, therefore, conducted. A series of runs was made with the empty vehicle approaching the low-friction test area at 47 km/h and the driver braking using the treadle valve. Runs were made using various application pressures, to the point where groups of wheels locked. The driver was instructed not to attempt to counter any loss of control, except as necessary to avoid hazard. The standard test procedure was followed [1].

The vehicle combination was evaluated primarily in terms of the yaw response of vehicle units, which is the heading angle of the vehicle unit (in degrees), with zero parallel to the original direction of travel. Any significant yaw seen in this manoeuvre arose from lateral/directional instability of a vehicle unit.

The time history of a typical run that resulted in loss of control is shown in Figure 11. The brake application of about 193 kPa (28 psi) caused the tractor to jackknife to the left. The driver released the brakes and steered out of the manoeuvre without coming to a complete stop. The remainder of the vehicle remained straight. He probably would not have been able to arrest the jackknife at a higher speed. If the tractor front axle brakes had been used, it is probable that the tractor would not have jackknifed at this speed.

A summary of peak vehicle responses from the runs is shown in Figure 12 as a function of average treadle valve pressure.

4.6/ Evasive Manoeuvre

The object of this test was to evaluate empty vehicle lateral/directional characteristics at the limits of stability on a low-friction surface. A series of runs was made where the driver made an evasive manoeuvre, which is considered representative of a high-speed accident avoidance situation on a two-lane, two-way highway. The test used gates of 22.5 m (73.8 ft) for the lane change to the left and the return to the original lane, separated by 20 m (65.6 ft) in the left lane. The runs were made in accordance with the standard test procedure [1].

The vehicle combination was evaluated primarily in terms of the lateral

acceleration and yaw responses of the vehicle units. These are shown in Figure 13. Each response is the peak-to-peak amplitude experienced by the vehicle in the manoeuvre. The lateral acceleration of all units of the train increased to 54 to 57 km/h and then levelled off, indicating sliding. The tractor heading amplitude tended to decrease with speed, whereas the lead trailer's heading appeared to remain constant. These two components appeared to remain under control at all speeds. Trailers 2 and 3 showed an increase in heading angles, indicating slide while re-entering the original lane. At a speed of 54 km/h, the second dolly was jackknifing during the return to the original lane, which resulted in rear trailer swing. This was a consequence of the rearward amplification of lateral acceleration, discussed in Section 4.7 for the loaded vehicle. A typical run at 54 km/h is presented in Figure 14 The dolly jackknife is evident in the dolly 2 hitch angle trace, at a time of 10 s, and the trailer 3 articulation clearly shows the subsequent trailer swing. The vehicle is shown in this manoeuvre in Figure 15.

4.7/ Sinusoidal Steer

The objective of this test was to evaluate characteristics of rearward amplification of lateral acceleration for this combination. A series of runs was made where the driver made a sinusoidal steer input to the vehicle while travelling at a steady speed, in accordance with the standard test procedure [1]. This test was conducted at speeds of 63, 84, and 94 km/h, with steer input periods between about 2 and 5 s. The vehicle is shown in this manoeuvre in Figure 16.

The vehicle combination was evaluated in terms of the lateral acceleration responses of the vehicle units. Lateral acceleration gains of the trailers are presented in Figure 17, as a function of tractor steer input period for the three test speeds. Each gain is defined as the peak-to-peak trailer lateral acceleration response divided by the peak-to-peak tractor lateral acceleration, and is dimensionless.

It is evident from Figure 17 that rearward amplification increases with speed. It also increases rearward by trailer, for the two highest speeds. It is of interest, however, to see that there is little increase in lead trailer amplification with speed, which shows how little influence the other trailers have on this unit. Rearward amplification is also somewhat sensitive to steer period reaching the highest value at around 2 to 3 s. The results show that, at highway speed, the A-train triple is a very responsive vehicle. The reason for this is that its

inherent stability is rather low. Stability and response of mechanical systems have an inverse relationship. High stability means low response to input and vice versa.

Figure 18 shows the vehicles' responses from a typical run with a steer period of about 2.5 s at 94 km/h. This run illustrates well the increase, or amplification, rearward by trailer from the tractor. Notice, also, how the response of each trailer rearward lags behind the steer input at the tractor, nearly 2 s for the rear trailer. It can be seen that this trailer's peak response occurs some time after the driver completes the the steer input, and nothing the driver can do in the interim will affect the amplitude of the response. Indeed, if the response is close to the limits of this trailer's stability, any action by the driver to try and effect recovery might only increase the response. This lag is due to the number of articulation points and the length of the vehicle and is considered to affect adversely the driver's control of the vehicle.

Figure 19 shows rear trailer responses from typical runs with a steer period of about 2.5 s at each test speed. At 63 km/h the response is nearly deadbeat; at 84 km/h the rear trailer is clearly oscillating; and at 94 km/h the rear trailer is oscillating strongly. Those three time histories clearly depict the reduction in damping of the vehicle's lateral/directional response.

The responsiveness of this vehicle made this and other tests difficult to conduct:

1/ On approach, small steer corrections made by the driver were amplified rearward so that a desired steady period before the manoeuvre was rarely achieved. This made data detrending difficult [1] and may account for a certain amount of scatter in the data.
2/ The response to the manoeuvre itself continued to the point where the driver had to exit the test area; a complete response could not be obtained because the test area was simply not large enough.
3/ The steer inputs were very small, typically 25 to 35° of steering wheel angle, which is less than 1° steer at the front axle. This small steer resulted in a tractor lateral acceleration of about 0.1 to 0.15 g.

A rearward amplification of 3.0 did, on occasion, result in substantial trailer roll and sometimes trailer swing, even on the high-friction surface, as may be seen in Figure 16. However, tempering the steer input to

avoid excessive rear trailer response resulted in such a small steer input that, while it was closely sinusoidal at the steering wheel, it was often rather poorly balanced at the front axle. The reason for this is probably backlash, compliance, and non-linearity within the steering system itself. A carefu' inspection and some tests of the steering system showed no evident defect or bias. The steering system had previously been inspected and aligned when the tires for the test program were installed. The front axle steer, however, is the actual input that causes vehicle response. Responses, therefore, were often not well balanced, which means that the steer input contained, perhaps, substantial other periodic content besides the intended steer period.

It is for this reason that the rearward amplifications were computed as the ratio of peak-to-peak trailer lateral acceleration response to peak-to-peak tractor lateral acceleration. This significantly reduced the scatter in the results and avoided the issue of whether the first, second, or highest input and response peaks should be used as the basis for these ratios. Nevertheless, because the input was often unbalanced and not a pure sine wave, it was likely that the response was somewhat attenuated compared to what would result from a pure sine wave. The data presented in Figure 17 are, therefore, considered optimistic, in the sense that they are probably lower than would arise from a perfect steering system or a computer simulation of the vehicle using a pure sine wave steer input.

Tests were only conducted to 94 km/h. It is our opinion that this vehicle would be even more responsive at a typical highway speed limit of 100 km/h. Actual speeds are often higher than this limit, and the vehicle would become yet more responsive if actual speeds did exceed 100 km/h. Despite the enviable safety record achieved by some special permit operations using A-train triples, this configuration cannot be recommended when the comparable C-train is so much less responsive [6]. The response characteristics of this vehicle were found to be much different from those of the comparable C-train, which was found to be much more stable [6].

4.8/ Lane Change

The objective of this test was to evaluate vehicle dynamic stability characteristics in a dynamic manoeuvre. A series of runs was made where the driver made a lane-change manoeuvre considered representative of a high-speed accident avoidance situation on a four-lane or divided

highway. The runs were made in accordance with the standard test procedure [1].

The test used a gate of 30 m (98.4 ft) for the lane change. This was used to provide a vehicle speed of about 80 km/h, which is a typical speed limit and might permit some comparison of the results of this test with those described in the preceding sections

The results from all the runs are summarized in Figure 20. The peak-to-peak lateral acceleration, roll, and yaw (or heading) angles all showed an increase as the limiting speed of 74 km/h was reached, at which point the rear trailer was rolled rather violently to the left and slid about 1 m to the left into the adjacent lane. While the trailer did not roll over in this manoeuvre, it undoubtedly would have if its centre of gravity had been higher and, perhaps, at a somewhat lower speed than 74 km/h. Lateral acceleration and roll gains are also shown in Figure 20. The lateral acceleration gain was computed by the same method as rearwrad amplification and is consistent with the results obtained there by interpolation. The yaw overshoot of the trailer is also shown in Figure 20, which clearly illustrates the rear trailer swing at the limiting speed. Figure 21 shows selected vehicle responses in a run at 75 km/h, where trailer swing was encountered. The swing is evident in the rear trailer yaw angle overshoot, around 8 s, and the trailer roll to the left, which reached 6°. The vehicle is shown in Figure 22 at about this point in that run. Note that the outrigger did not touch down.

4.9/ Normal Straight-Line Driving

The objective of this test was to attempt to evaluate lateral motion of the rear trailer of the combination, the phenomenon known as trailer sway. A series of runs was made with the loaded vehicle driven normally at 94 km/h in a straight line, according to the standard test procedure [1].

As previously mentioned, the vehicle was very responsive and even the slight steer corrections made in the course of normal driving, and roughness of the test track surface, resulted in rear trailer sway that was strongly perceptible to the occupants of a chase vehicle. Root mean square (RMS) lateral acceleration of the rear trailer was 3.37 g/° of RMS steer input. RMS sway of the rear of the rear trailer relative to the tractor steer axle was 418 mm/° (16.5 in/°) of RMS steer input. This value is suspect because of the small articulation angles.

4.10/ Steady Circular Turn

The objective of this test was to evaluate vehicle steady-state rollover characteristics to determine the high-speed offtracking of the vehicle and to examine the side loads exerted on the tractor by the trailers. A series of runs was made with the vehicle circumscribing a circle with a 50 m (164 ft) radius at a steady speed, according to the standard test procedure [1].

The vehicle is shown in this manoeuvre in Figure 23. The vehicle combination was evaluated primarily in terms of the roll response of the vehicle units. Average steady-state roll angle is presented in Figure 24 as a function of tractor lateral acceleration. Roll angles increased with speed. However, the trailer centre of gravity was not high enough for the rollover point to be reached in this test. Rollover of the rear trailer would normally be expected with this vehicle, because the payload centre of gravity would usually be considerably higher than that of the vehicle as tested. Average steady-state articulation angles are shown in Figure 24. These decreased modestly with increase in lateral acceleration, and as a consequence, the offtracking decreased.

The lateral force experienced by the tractor fifth wheel is also shown in Figure 24, as a function of tractor lateral acceleration. This shows a gradient of 33.4 kN/g (7500 lb/g).

At the limiting speed of 54 km/h, a peak lateral acceleration of 0.50 g, the rear trailer swung out and the driver departed from the circular trajectory, as shown in Figure 25.

5/ DISCUSSION

Tests were conducted with the equipment as provided. No efforts were made to modify the equipment, except as required for testing, and these modifications did not affect vehicle operation.

Tests were conducted in various weather conditions. Tires wore progressively as the various tests were conducted. The outrigger assembly was additional to normal trailer equipment, and the characteristics of the trailers were, therefore, somewhat atypical, in both empty and loaded conditions. In both conditions, the centre of gravity was somewhat lower than normal, particularly for the loaded condition, because of the underslung outriggers.

It is not possible to make any meaningful remarks on the effect these factors might have had on the results, except for centre of gravity height, which has been mentioned already where it may have affected the results. The effect of raising the trailer centre of gravity to 1.20 m (4 ft) above the trailer floor from 0.33 m (13 in) for this vehicle would be to reduce the vehicle's roll threshold to, perhaps, 0.30 g [15]. This would have reduced the limiting speed in the steady circular turn and resulted in dynamic rollover in the lane change. The results presented pertain to the particular vehicle tested, and results different in some respects might be obtained for another vehicle at another time.

This vehicle was considered an easy vehicle to drive by the test driver. The short trailer wheelbase and single axle made it easy to manoeuvre in both low-speed turns and dynamic tests, as the trailer imposed rather modest forces on the tractor. However, because it was so responsive it was very easy for the driver to create a trailer swing situation, and this would have been a rollover situation with a higher trailer centre of gravity. The driver had no feedback of second- or third-trailer response once a manoeuvre had started, because the A-dolly hitch does not transmit trailer roll moment forward. Once the driver had made an excessive input, there was nothing that could be done to alleviate trailer response, because rear trailer response lagged 1.5 to 2.0 s behind the steer input. The responsiveness of this vehicle in normal driving, particularly when empty, was a concern because rough roads excited considerable trailer sway. Even hauling two trailers to the test site on delivery was not a pleasant experience.

6/ CONCLUSIONS

An A-train triple trailer combination was tested by the Ontario Ministry of Transportation and Communications, as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with an empty vehicle on a low-friction surface and a loaded vehicle on high-friction surface.

The length of this vehicle clearly contributed to the significant space required to make turns. Since such vehicles only operate by special permit, however, this may not be a major issue because the permit usually limits where the vehicle may go.

The air brake system was relatively fast and well balanced, largely because of the valves used. Booster relay valves on the dollies made a major contribution to this.

The lateral/directional stability of the vehicle was poor, both empty on a low-friction surface and loaded on a high-friction surface. Stability was clearly deteriorating fast at the highway speed limit of 100 km/h. The vehicle was so responsive, with a rearward amplification of lateral acceleration of nearly 3, that it was easy to cause a trailer swing. The A-train triple configuration is considered undesirable because of its low stability at highway speeds. The C-train configuration is preferable from this point of view, as demonstrated in a parallel series of tests. The roll stability was high because the centre of gravity of the trailer was quite low. A higher centre of gravity would have reduced the roll threshold significantly.

7/ REFERENCES

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[2] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: 45 ft Semi," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-02, June 1986.

[3] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: A-Train Double," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-03, June 1986.

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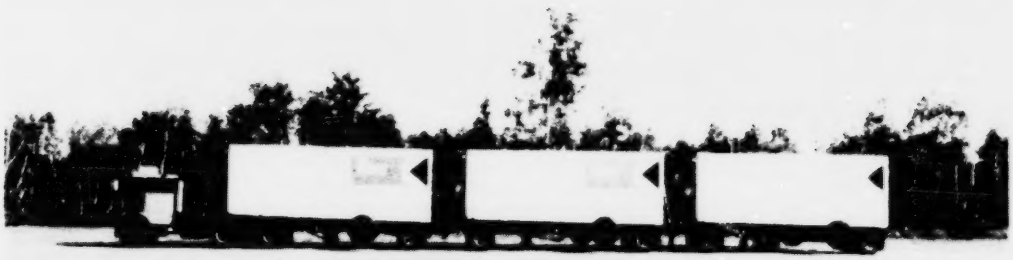


Figure 1/ A-Train Triple, View of Vehicle

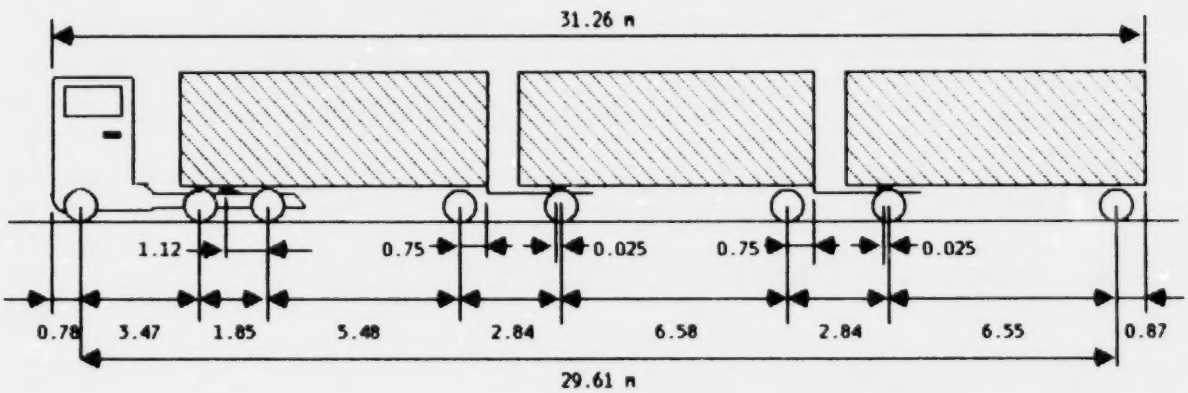


Figure 2/ A-Train Triple, Vehicle Dimensions

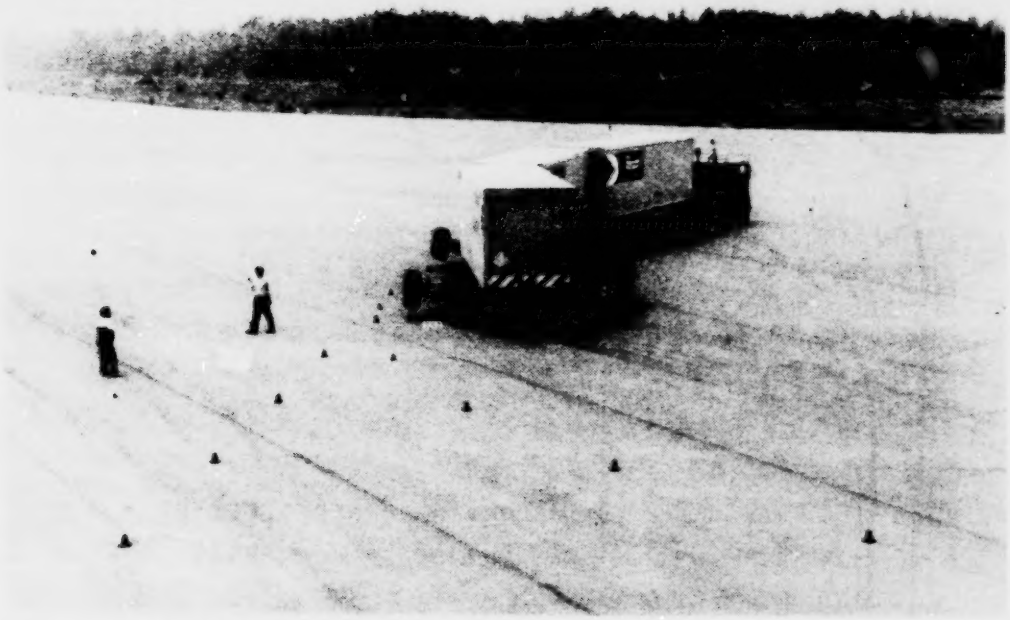
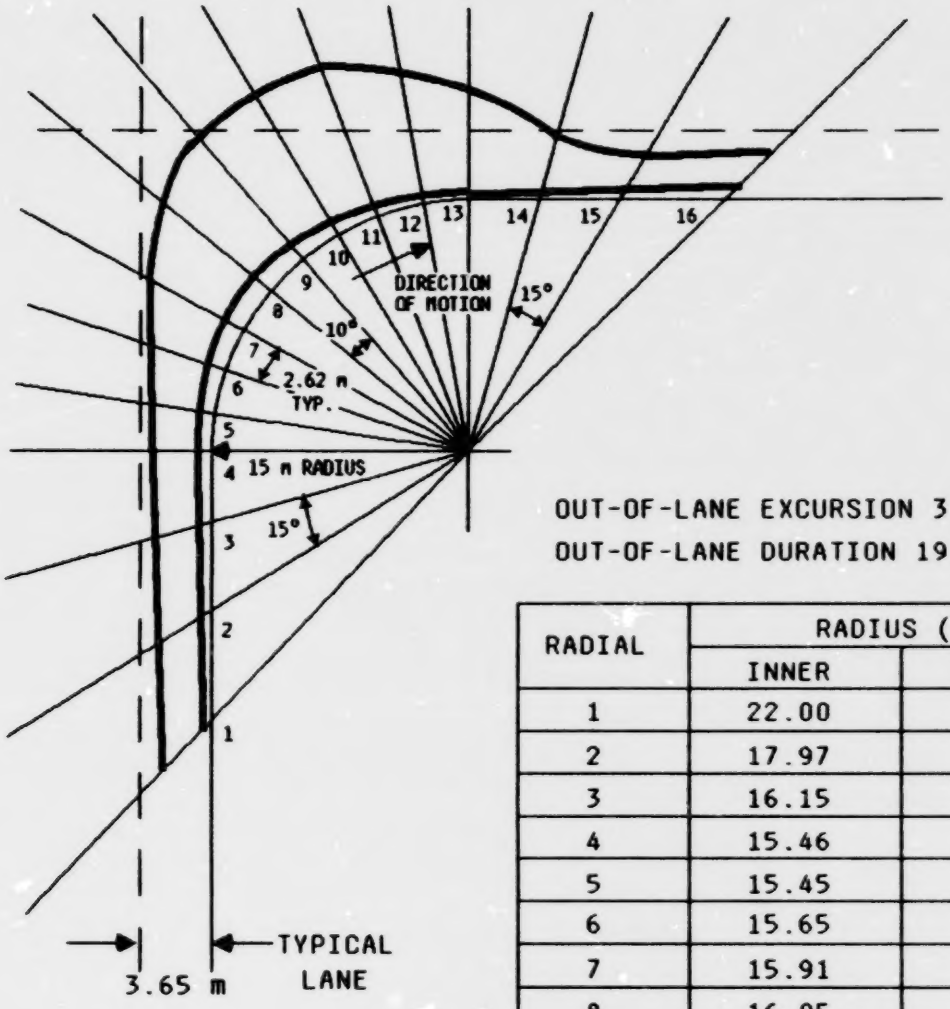


Figure 3/ A-Train Triple,
Clockwise Offtracking

Figure 4/ A-Train Triple,
Counter-Clockwise Final Offtracking



OUT-OF-LANE EXCURSION 3.8 m

OUT-OF-LANE DURATION 19.4 m

RADIAL	RADIUS (m)	
	INNER	OUTER
1	22.00	25.40
2	17.97	20.77
3	16.15	18.67
4	15.46	18.09
5	15.45	18.37
6	15.65	19.20
7	15.91	20.86
8	16.05	22.72
9	15.98	23.98
10	15.73	24.49
11	15.46	24.14
12	15.29	22.83
13	15.37	21.11
14	16.05	19.32
15	17.95	20.16
16	-	24.77

Figure 5/ A-Train Triple, Right-Hand Turn Swept Path

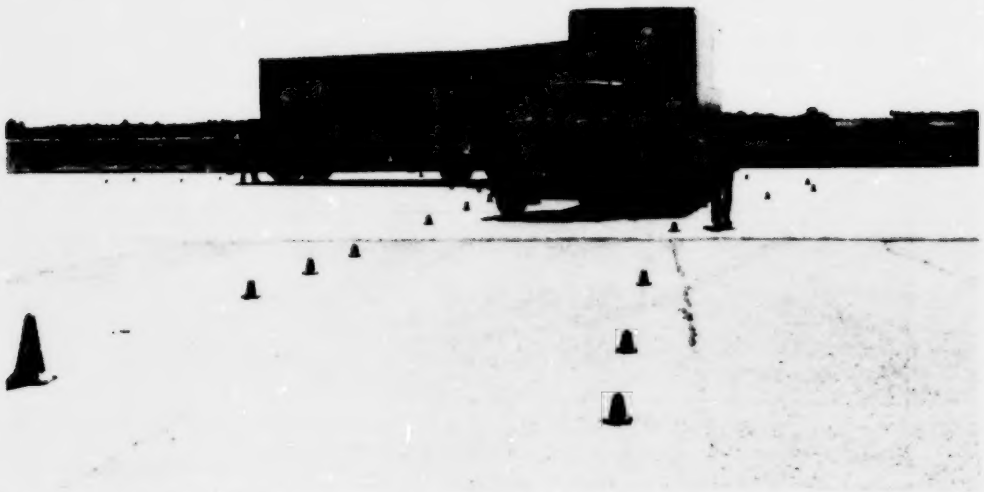
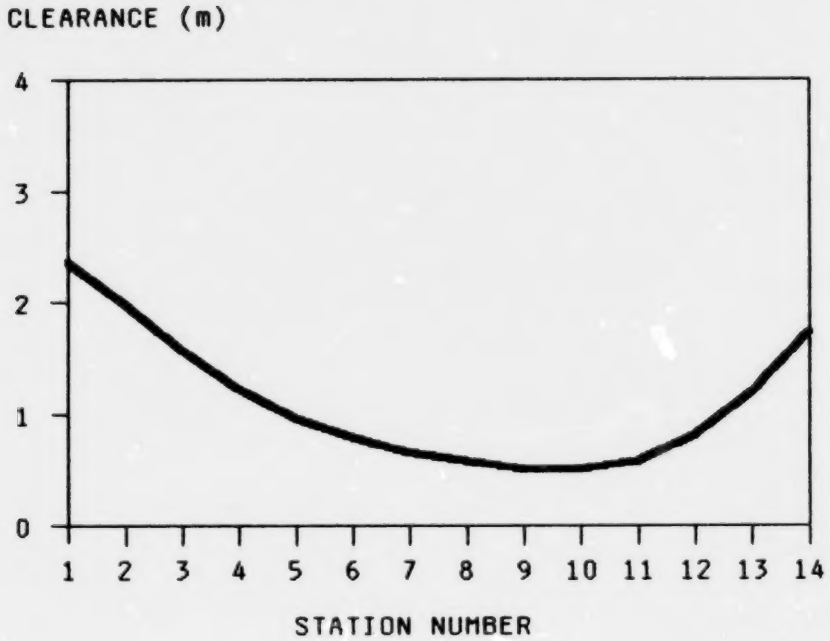


Figure 6/ A-Train Triple, Right-Hand Turn

Figure 7/ A-Train Triple, Channelized Right Turn



STATION NUMBER	CLEARANCE (m)
1	2.36
2	1.98
3	1.58
4	1.21
5	0.97
6	0.80
7	0.65
8	0.57
9	0.51 *(LOW)
10	0.52
11	0.59
12	0.81
13	1.20
14	1.74

Figure 8/ A-Train Triple, Channelized Right-Turn Clearance from Inner Curb

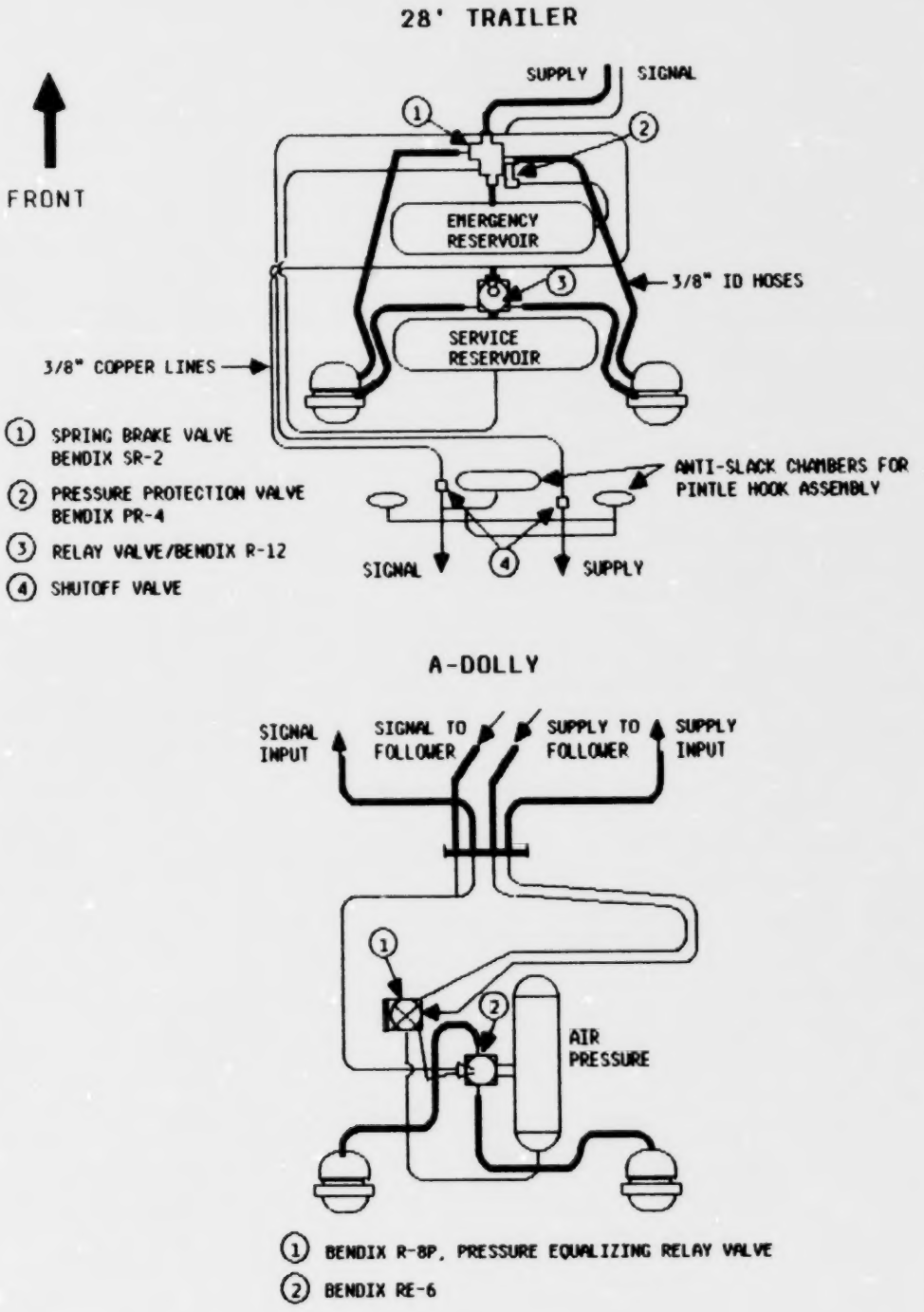


Figure 9/ A-Train Triple Trailer and Dolly, Air Brake System Schematic

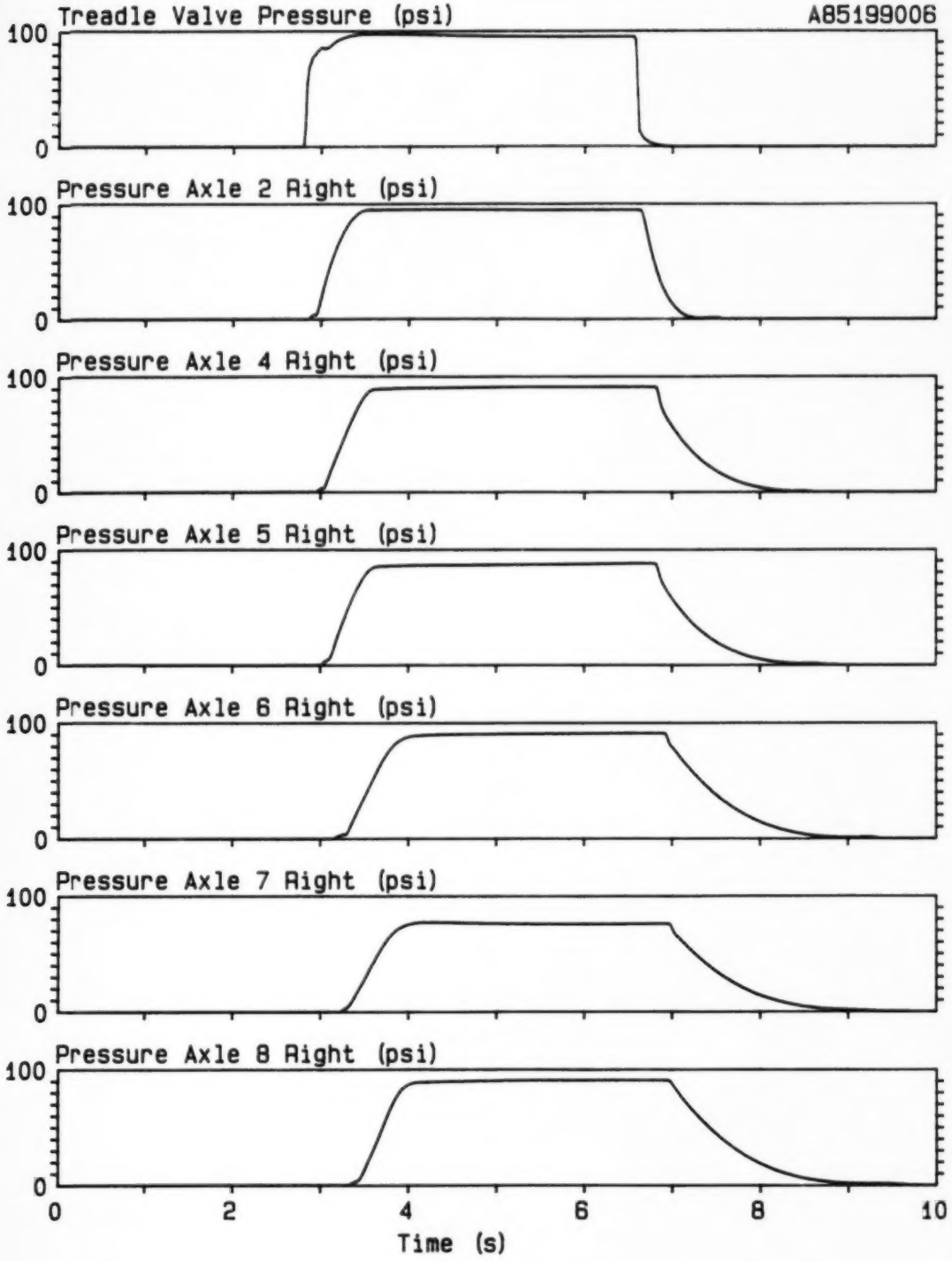


Figure 10/ A-Train Triple,

Air Brake Application and Release

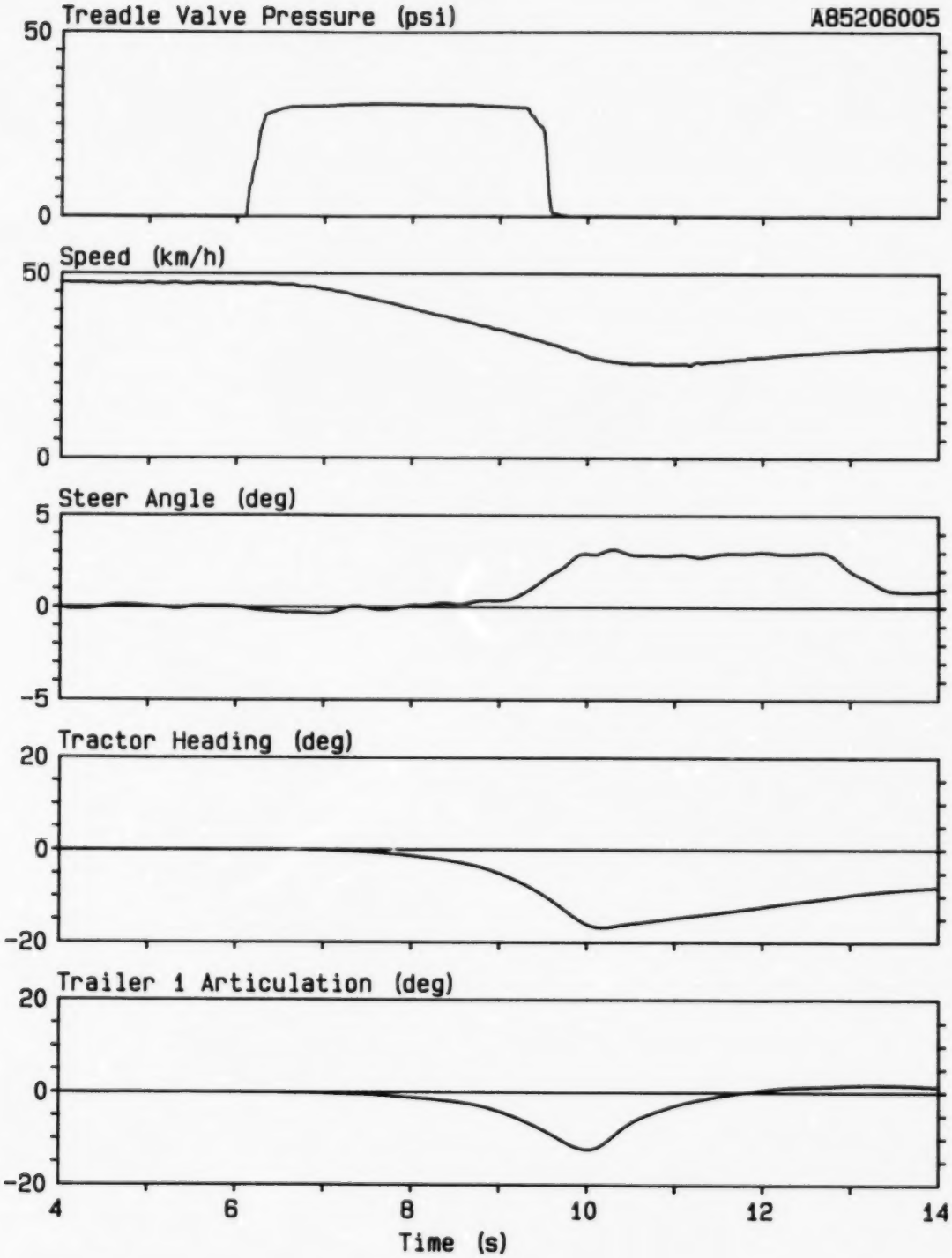


Figure 11/ A-Train Triple,

Vehicle Response to Straight-Line Braking

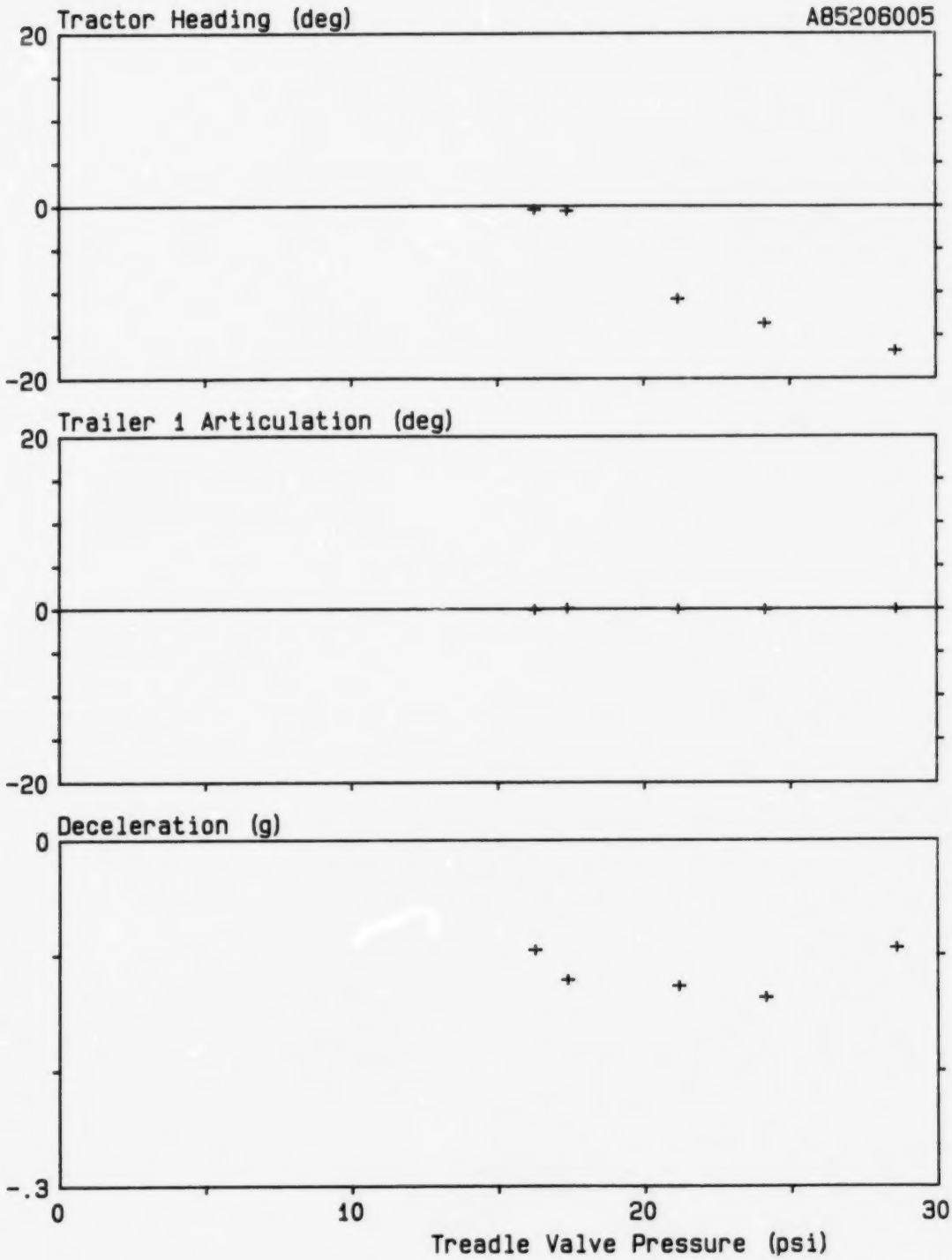


Figure 12/ A-Train Triple, Straight-Line Braking Responses vs Treadle Valve Pressure

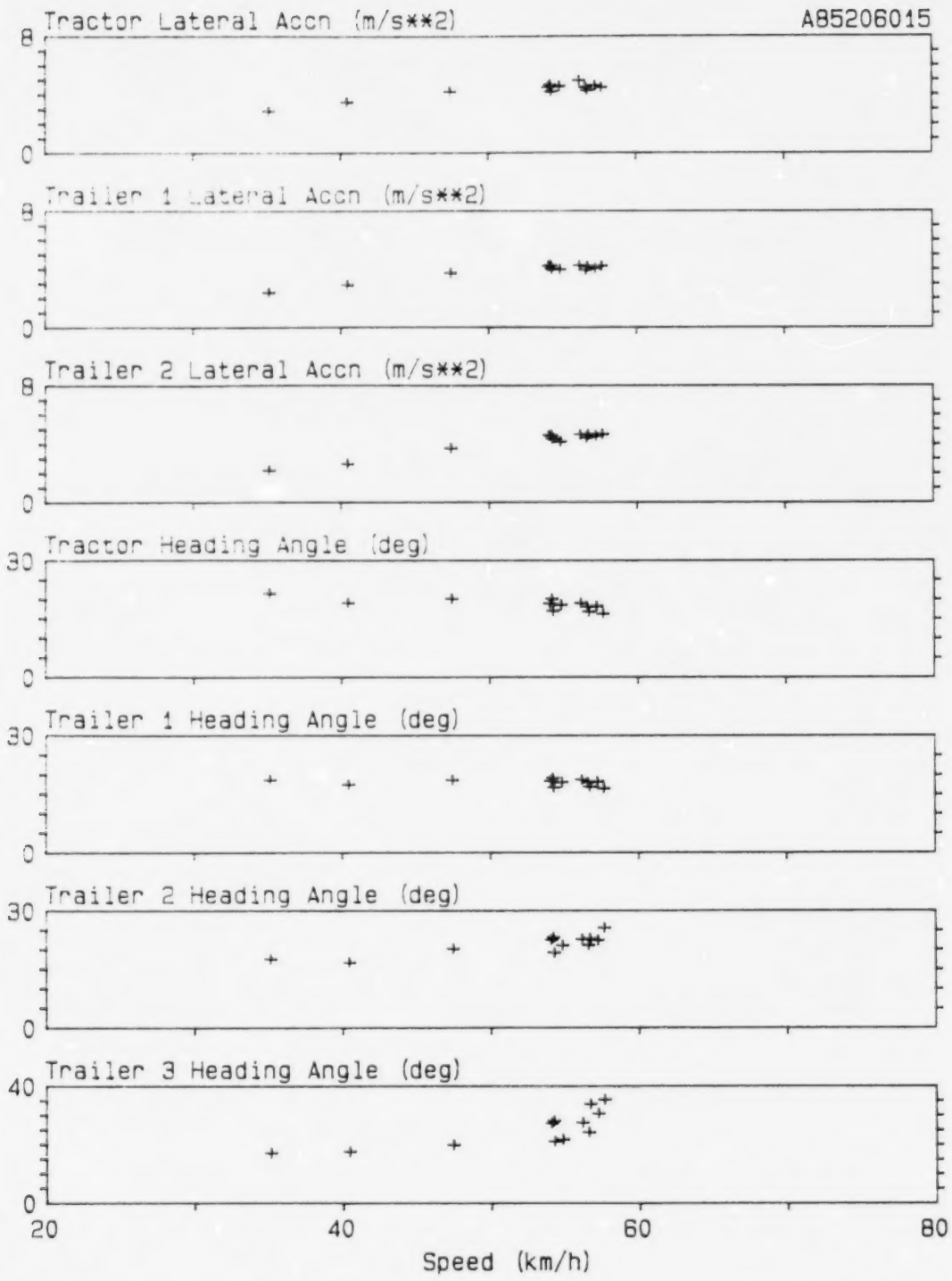


Figure 13/ A-Train Triple, Evasive Manoeuvre,

Peak-to-Peak Responses vs Speed

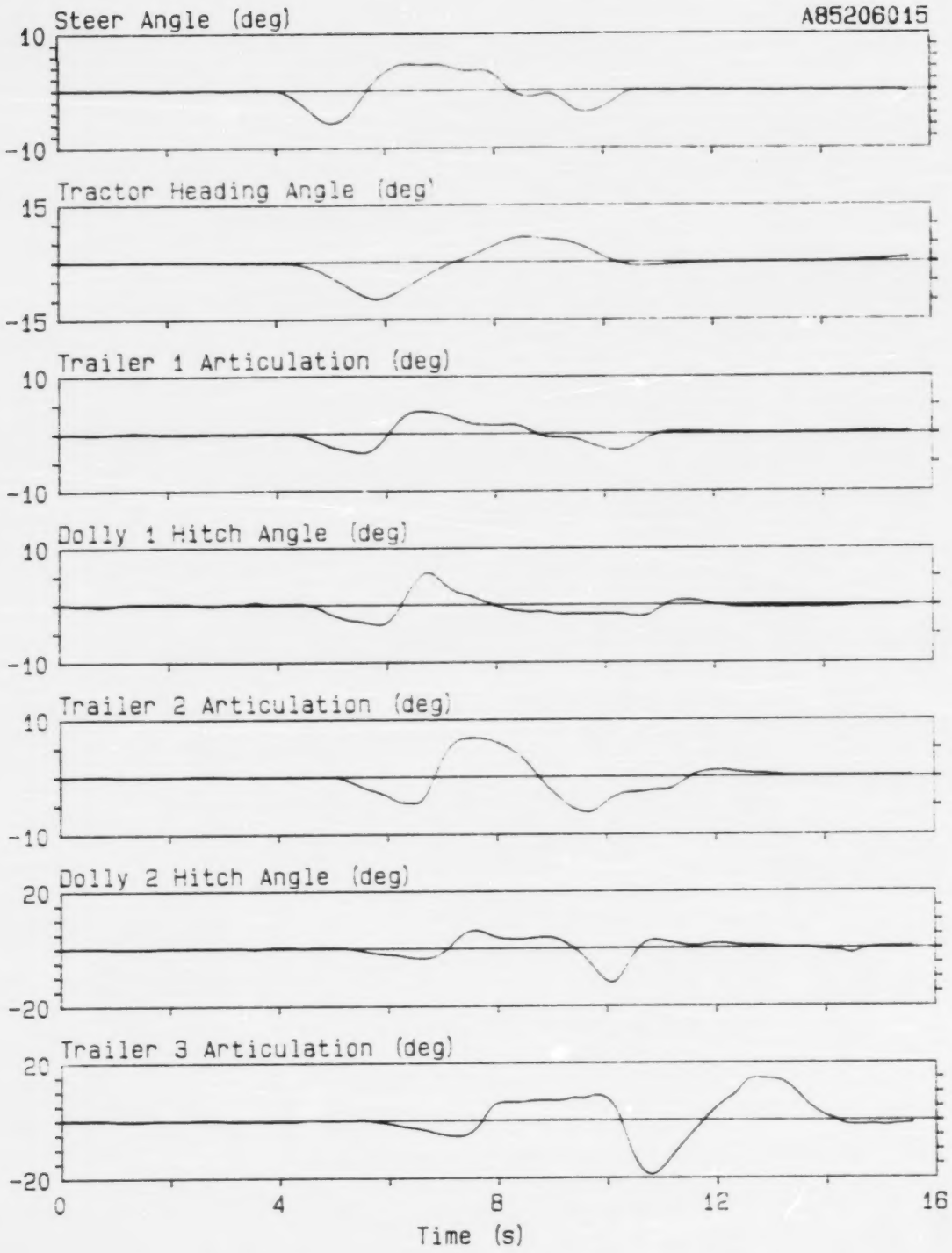


Figure 14/ A-Train Triple,

Vehicle Response in Evasive Manoeuvre

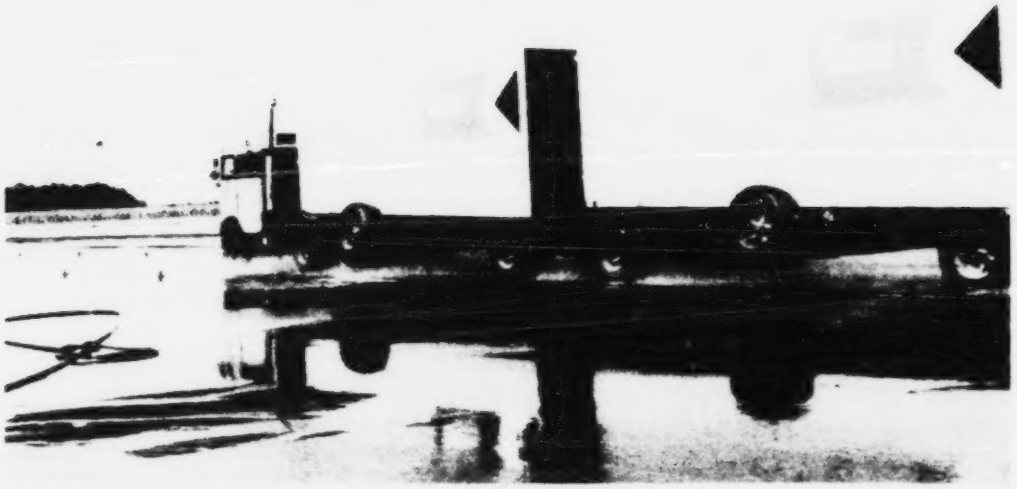


Figure 15/ A-Train Triple Vehicle Making
Evasive Manoeuvre

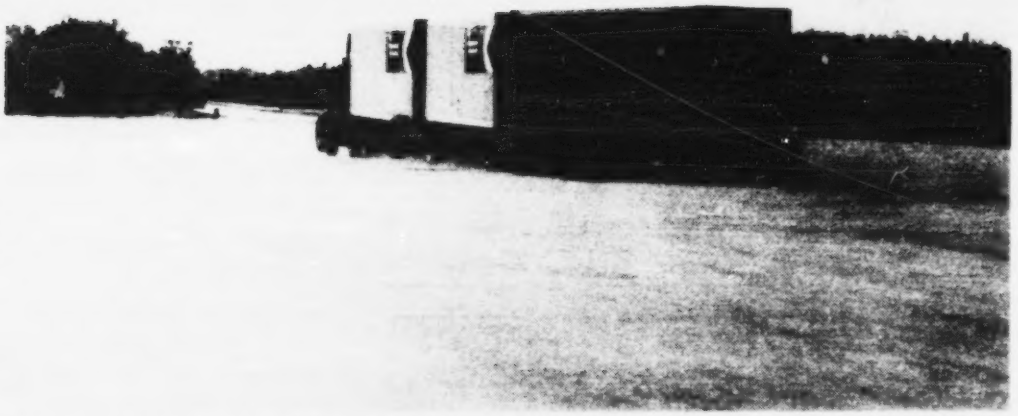


Figure 16/ A-Train Triple Vehicle Making
Sinusoidal Steer

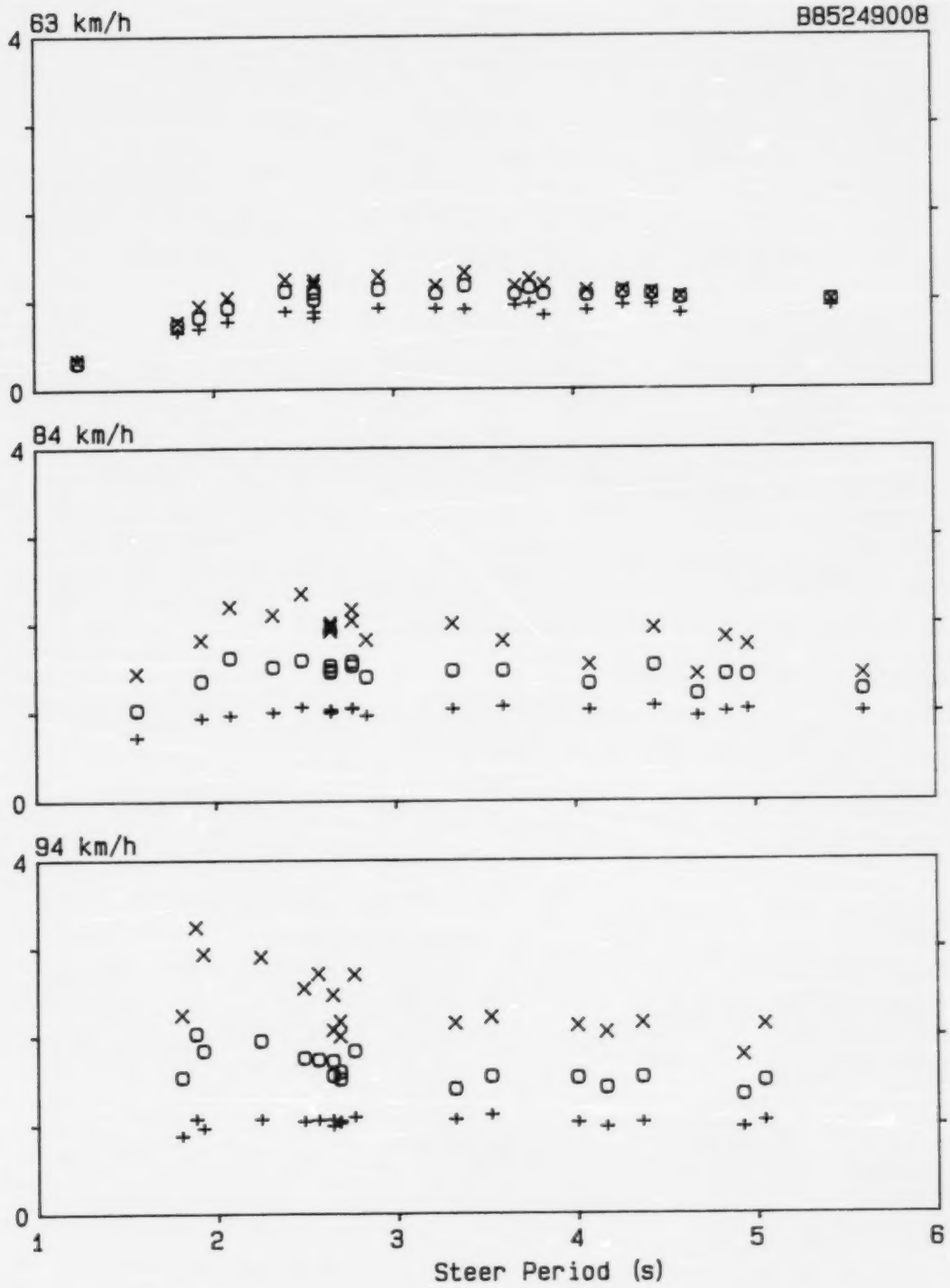


Figure 17/ A-Train Triple,

Rearward Amplification of Lateral Acceleration

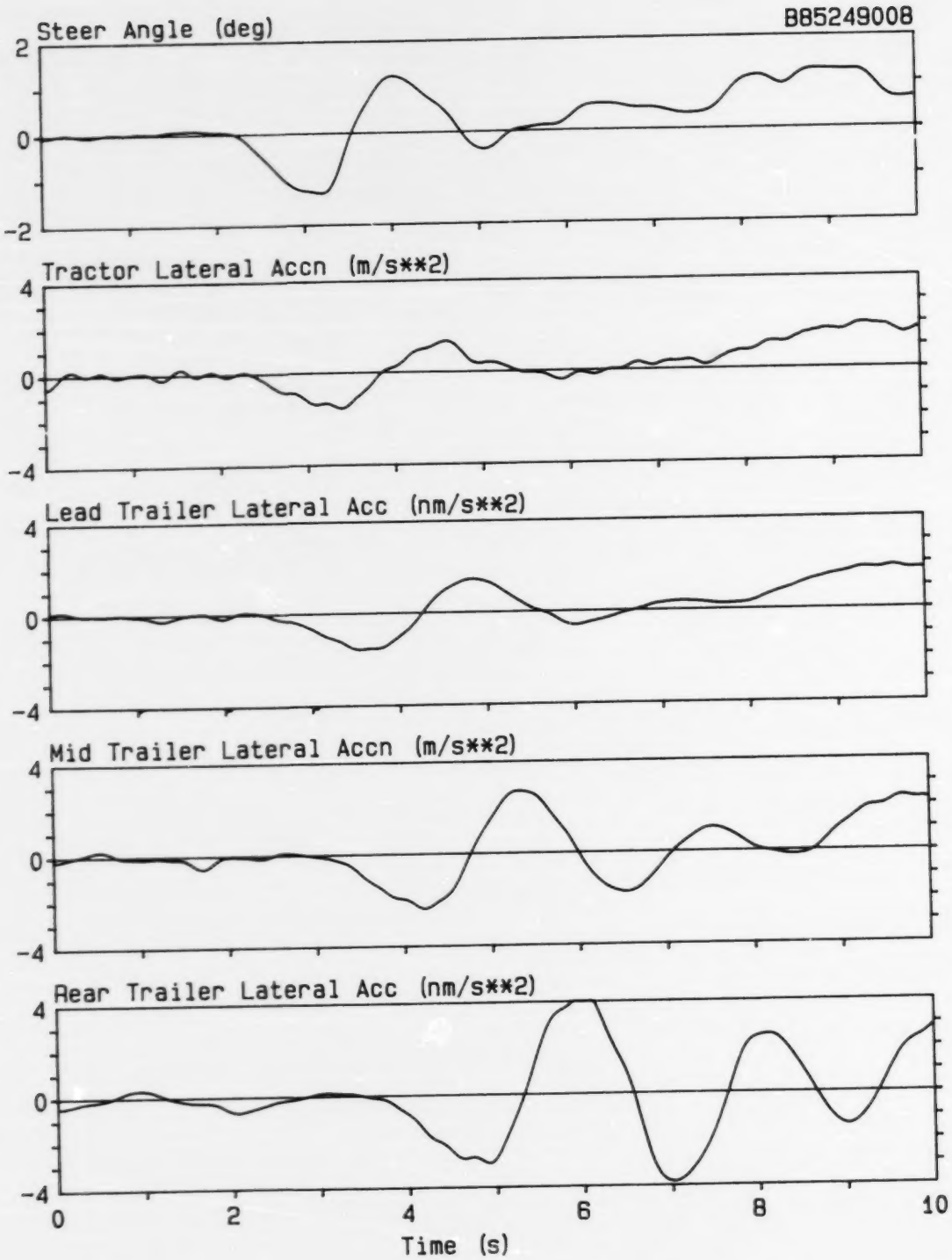


Figure 18/ A-Train Triple, Sinusoidal Steer,

Trailer Responses at 94 km/h

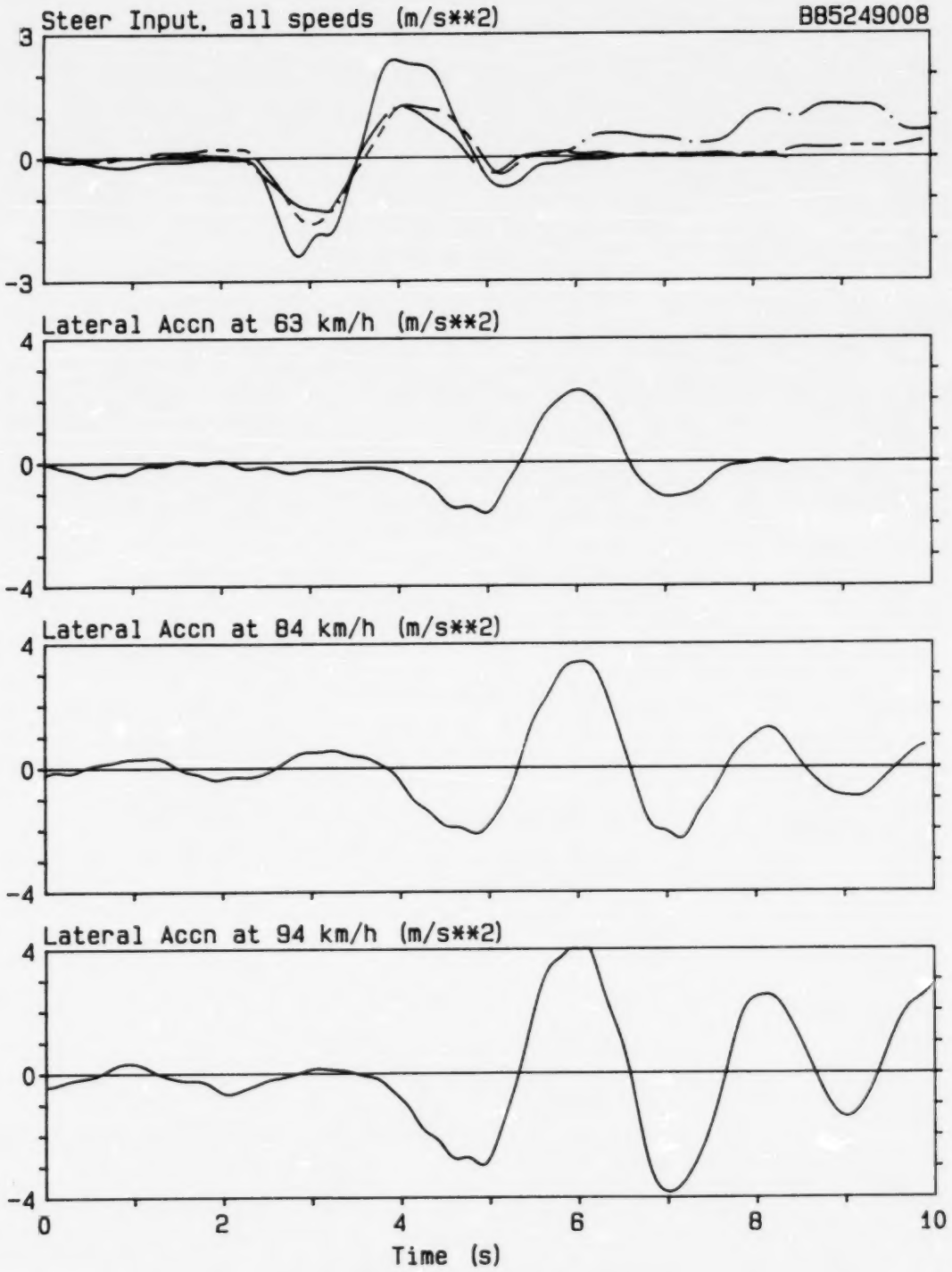


Figure 19/ A-Train Triple, Sinusoidal Steer,
Rear Trailer Lateral Acceleration, 3 Test Speeds

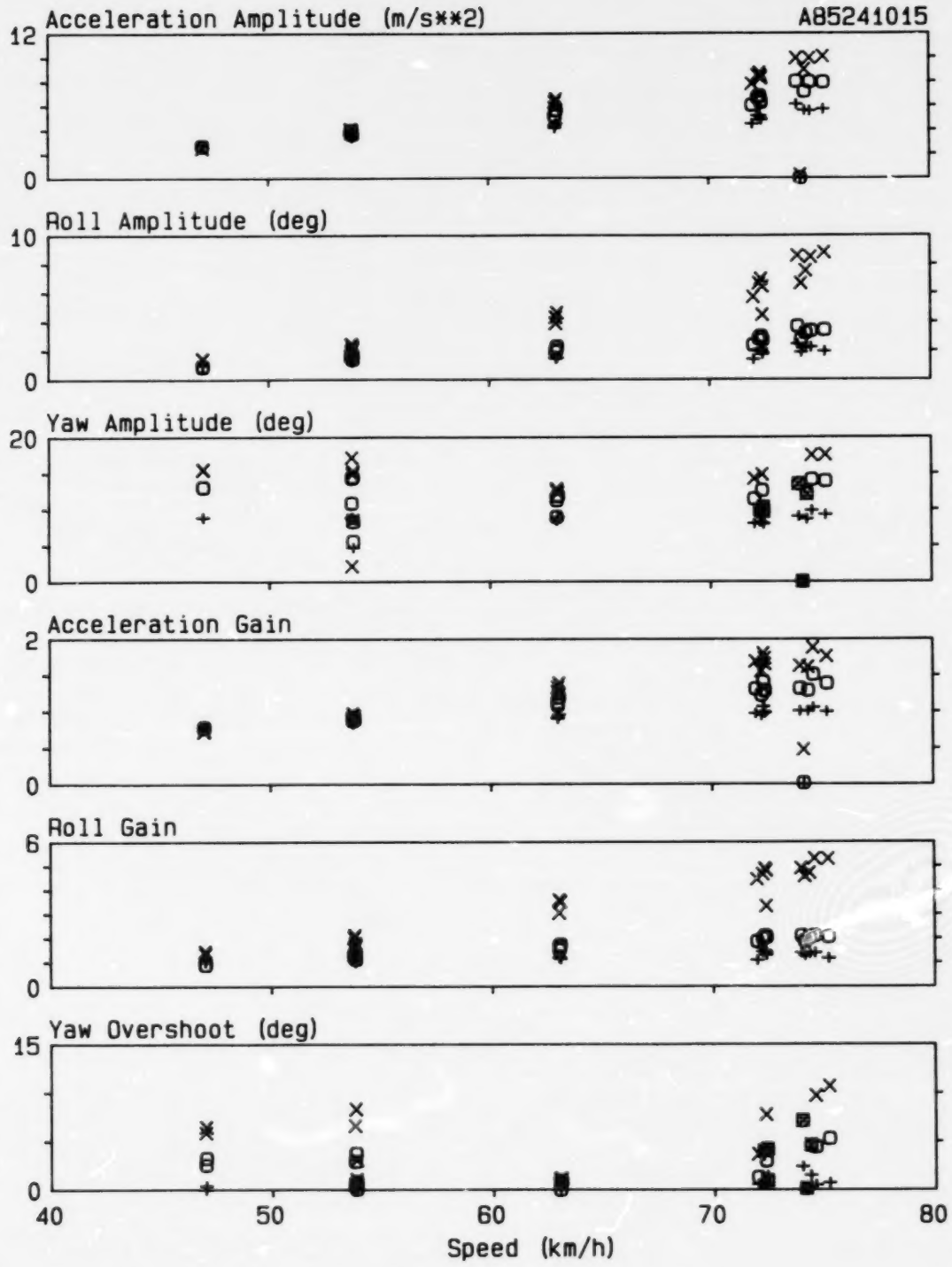


Figure 20/ A-Train Triple, Lane Change,

Response Summary vs Speed

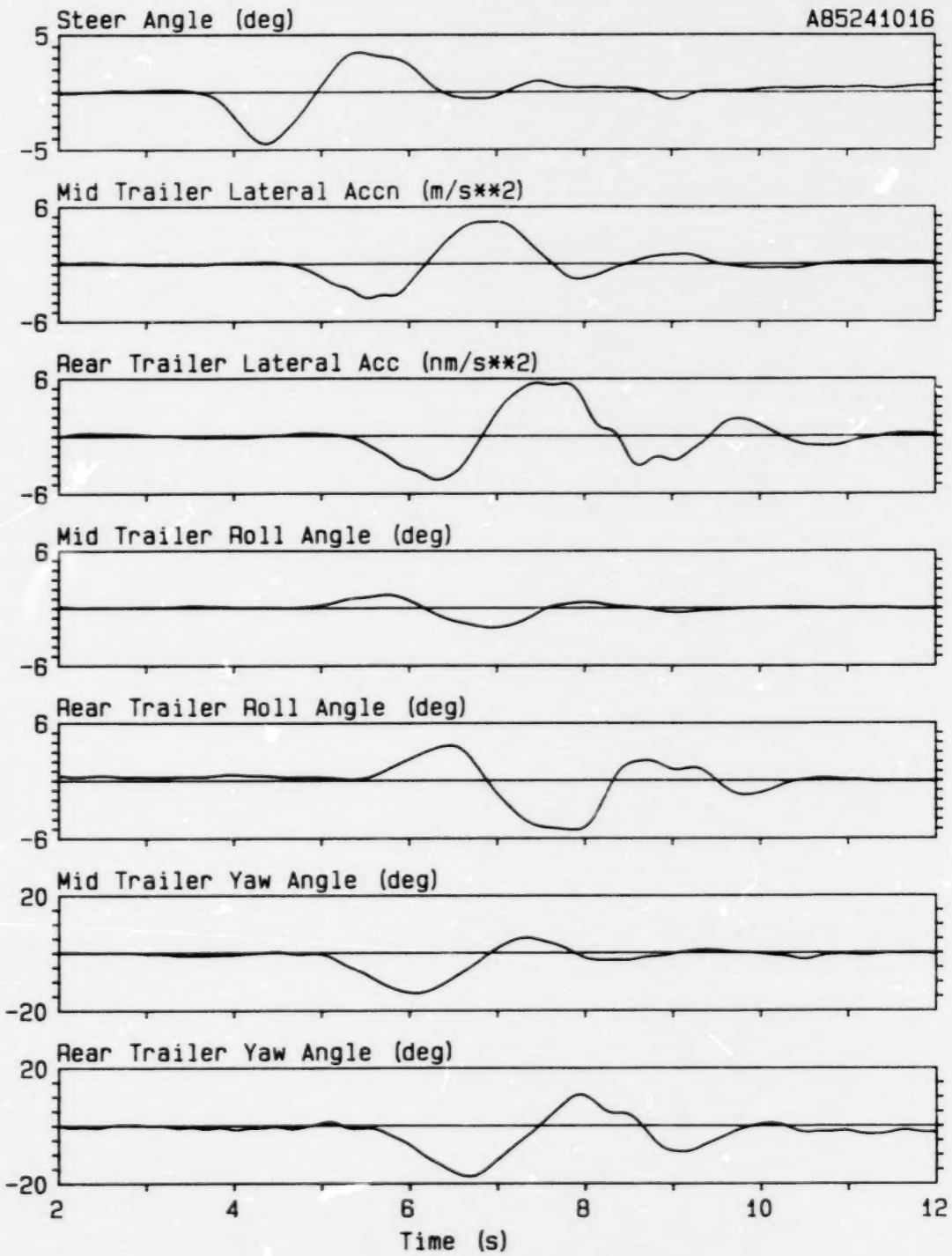


Figure 21/ A-Train Triple, Lane Change,

Vehicle Responses at 75 km/h

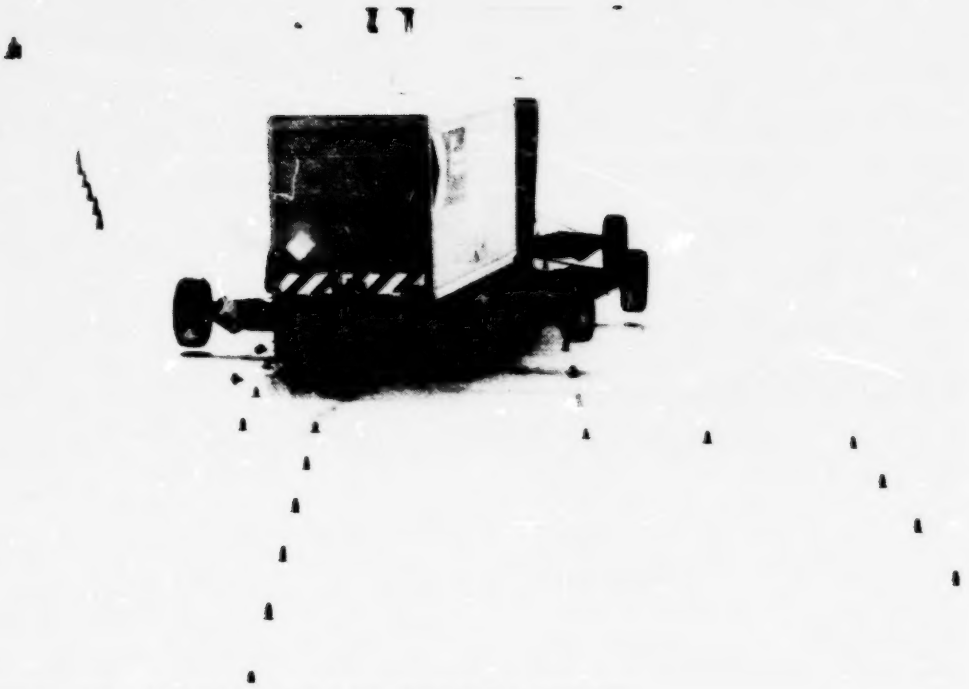


Figure 22/ A-Train Triple Vehicle Making
Lane Change

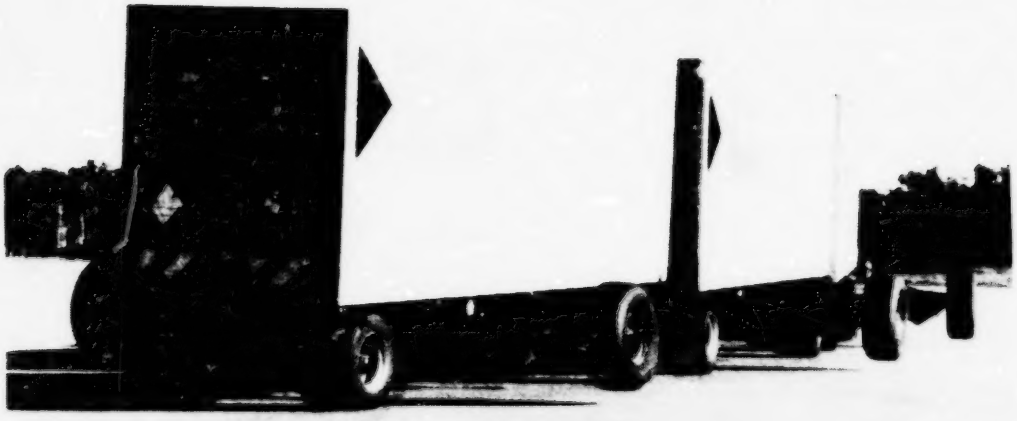


Figure 23/ A-Train Triple Vehicle Making
Steady Circular Turn

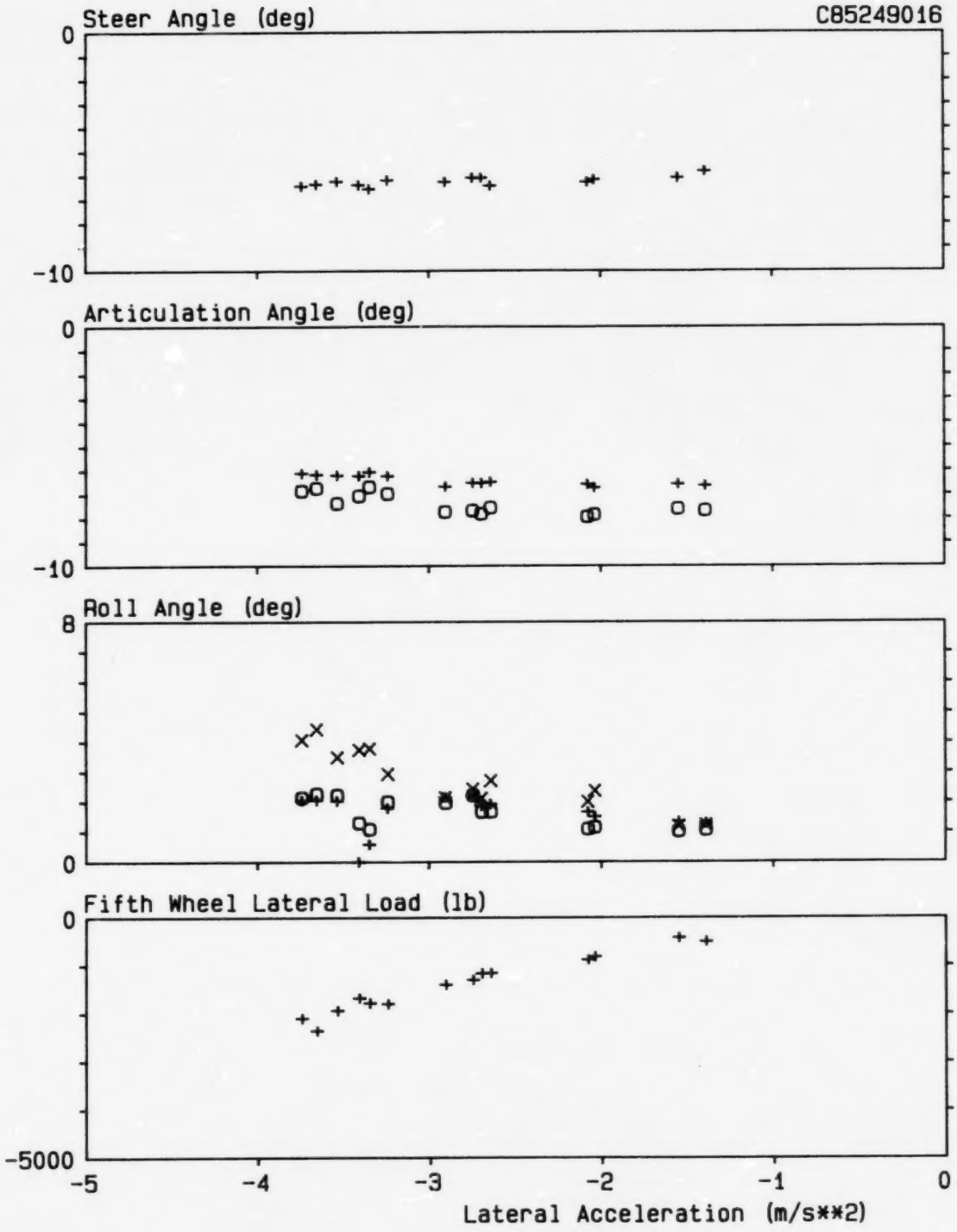


Figure 24/ A-Train Triple, Steady Circular Turn,
Vehicle Responses vs Tractor Lateral Acceleration

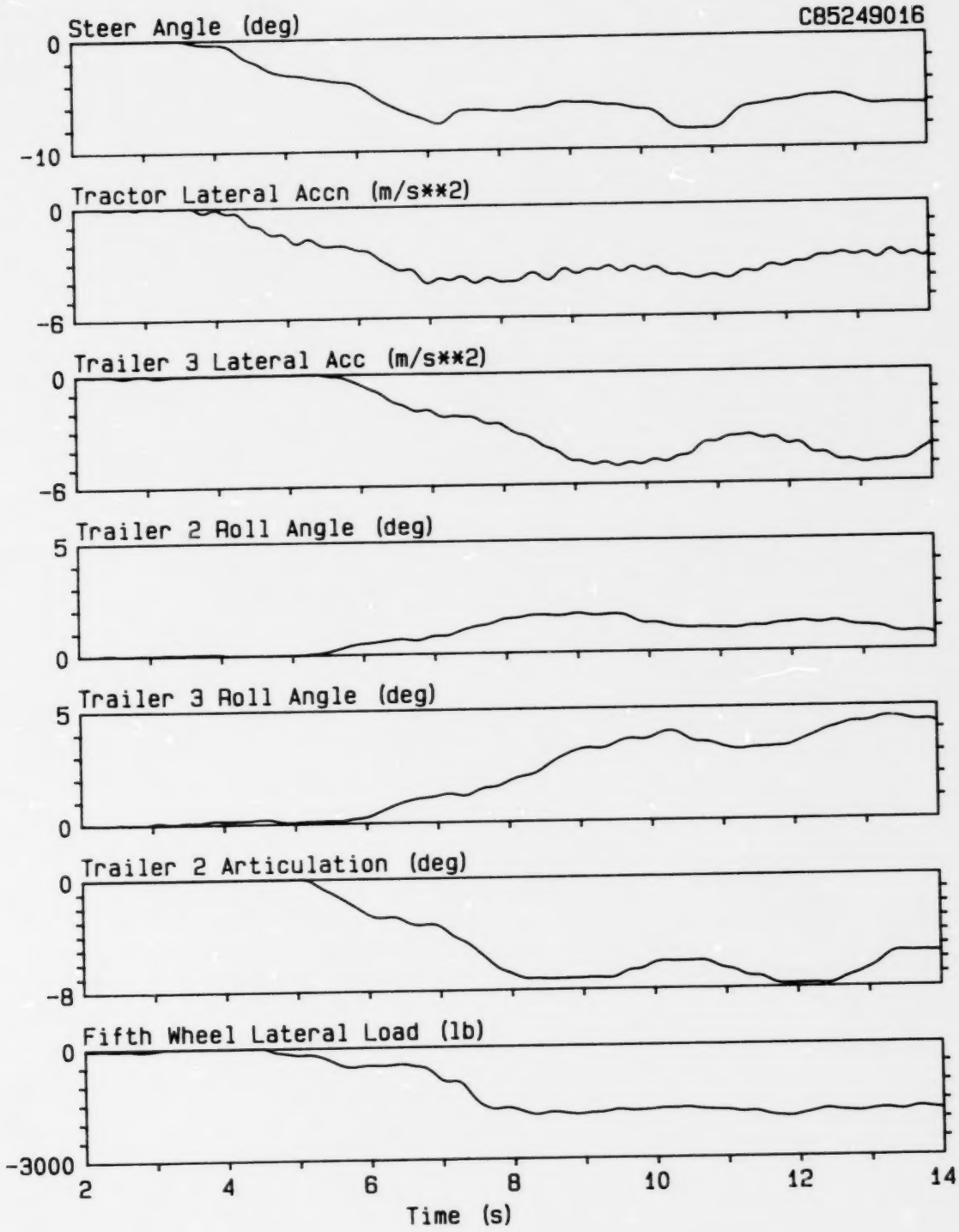


Figure 25/ A-Train Triple, Steady Circular Turn,
Vehicle Responses at 54 km/h